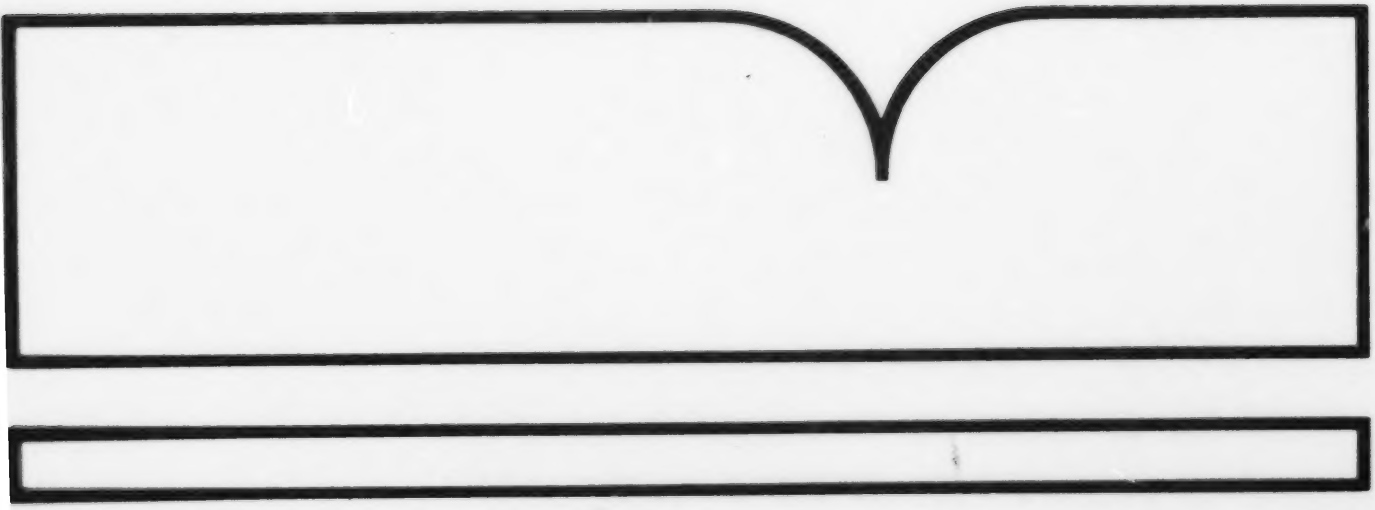
PB87-191557

Monitoring Radon Reduction in Clinton, New Jersey Houses

Research Triangle Inst.
Research Triangle Park, NC

May 87



U.S. Department of Commerce
National Technical Information Service
NTIS

EPA/600/D-87/162
May 1987

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Michael C. Osborne
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

and

Terry Brennan
Camroden Associates
RD #4, Box 62
Rome, New York 13440

and

Linda D. Michaels
Research Triangle Institute
P.O. Box 12194
Research Triangle Park, North Carolina 27709

EPA Contract 68-02-3992

EPA Project Officer
Michael C. Osborne

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-87/162		

4. TITLE AND SUBTITLE	5. REPORT DATE
Monitoring Radon Reduction in Clinton, New Jersey, Houses	May 1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
M. C. Osborne (EPA/AEERL), T. Brennan (Camroden Associates), and L. D. Michaels (RTI)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Research Triangle Institute P. O. Box 12194 Research Triangle Park, North Carolina 27709	11. CONTRACT/GRANT NO. 68-02-3992, Task 2
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711	Published paper; 4-12/86 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Michael C. Osborne, Mail Drop 54, 919/541-4113. Camroden Associates, RD No. 4, Box 62, Rome, NY 13440.

16. ABSTRACT The paper discusses EPA experience in monitoring radon reduction in Clinton, NJ, houses. Both the temperature-driven stack effect and typical household appliances (e.g., furnaces, whole-house fans, clothes dryers, and bathroom fans) were observed to reduce indoor pressure and potentially increase radon levels. Radon measurements obtained during cold weather, after residential heating systems were back in full operation, showed that the radon reduction techniques that were applied had been effective and that radon concentrations were significantly reduced. Although both grab sample and continuous monitor measurements were helpful in assessing radon entry sites and hour-to-hour fluctuations, respectively, only charcoal canister data collected under near-winter conditions could be used as a valid comparison with earlier March/April 1986 generated pre-radon reduction data.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Radon	Stationary Sources	07B
Residential Buildings	Indoor Air	13M
Monitors		14G
Atmospheric Contamination Control		06K

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	14
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

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INTRODUCTION

The discovery of high indoor concentrations of radon gas in the Reading Prong area of New Jersey, New York, and Pennsylvania, and elsewhere in the United States, has raised serious concerns about the expsoure of a large number of people to this radioactive gas. In response, the U. S. Environmental Protection Agency (EPA) has issued a booklet, "A Citizen's Guide To Radon: What It Is and What To Do About It."[1] EPA guidelines recommend initiating corrective action in houses with radon concentrations in excess of 4 picocuries per liter (pCi/l) of air. At radon concentrations of 200 pCi/l temporary relocation is recommended.

In the early spring of 1986, a preliminary survey of houses in Clinton, New Jersey, conducted by the New Jersey Department of Environmental Protection (DEP), identified more than 50 houses with indoor radon concentrations greater than 100 pCi/l in the subdivision of Clinton Knolls. Many of these houses had radon concentrations of 600 pCi/l or higher.

At the request of the New Jersey DEP, EPA's Air and Energy Engineering Research Laboratory, AEERL, initiated a project to develop and demonstrate cost-effective radon reduction techniques in 10 representative Clinton Knolls houses. Radon reduction was to be completed before the beginning of the 1986-1987 heating season to keep the exposure of residents to a minimum. Additional data were collected to add to the general body of information on radon transport and its control in houses; however, the data collected in this study were secondary to the pressing need of demonstrating effective radon reduction techniques in Clinton, New Jersey, before the fall of 1986.

The subdivision of Clinton Knolls is near the center of the town of Clinton, New Jersey. The neighborhood is dominated by frame houses with approximately 140 m^2 (1500 ft^2) of floor space. This uniformity is due to development of the subdivision predominantly by a single builder. Some custom-built houses, similar in style and size to the developer-built houses, are scattered among those built by the primary builder. Most of the houses are approximately 18 years old, and many of the 103 DEP survey houses are still occupied by their original owners, making this neighborhood unusually stable.

The development is built on a dolomitic limestone hill that rises above Main Street and ends at the edge of an abandoned quarry. The hill crests at the interior streets of the subdivision with some rock rising near the surface in the area. Several owners reported that the bedrock beneath their houses had to be blasted out before basements could be built or before sewer lines could be placed. Residents also reported the appearance of sinkholes throughout the neighborhood where the formation of underground caves had caused the earth to subside.

SELECTION OF DEMONSTRATION HOUSES

Owners of 103 houses who had participated in the DEP radon survey in March and April of 1986 were asked to volunteer their houses for the radon reduction demonstration effort. Of the volunteers, 56 were selected for screening. Figure 1 shows the locations of the 56 houses participating in EPA's radon screening effort, and Table I shows the range of radon concentrations for the 103 houses participating in the DEP radon survey.

The three basic floorplans repeated throughout the subdivision and a small number of diverse floorplans built by independent contractors were investigated. For the purposes of this paper, the floorplans have been assigned the following letter designations:

- Split-level with half basement - A (combination of slab-on-grade and block basement)
- Bi-level - B (slab-below-grade)
- Two story with no basement - C (slab-on-grade)
- Two story with basement - D (concrete-block basement)
- Independent builder floorplans - E (variety of substructures)

During a 1-week period, 56 houses were investigated by a diagnostic team of EPA and Research Triangle Institute personnel. The objective of the house screening effort was to characterize the pool of houses and select 10 houses as representative of the Clinton housing stock. These houses could then be used to demonstrate radon reduction measures.

Table I. Clinton radon levels.

Concentraction pCi/l	No. of Houses	% of Sample
>2048	2	1.9
1024-2047	3	2.9
512-1023	13	12.6
256-511	17	16.5
128-255	17	16.5
64-127	12	11.7
32-63	12	11.7
16-31	14	13.6
8-15	5	4.9
4-7	6	5.8
<4	2	1.9
	103	

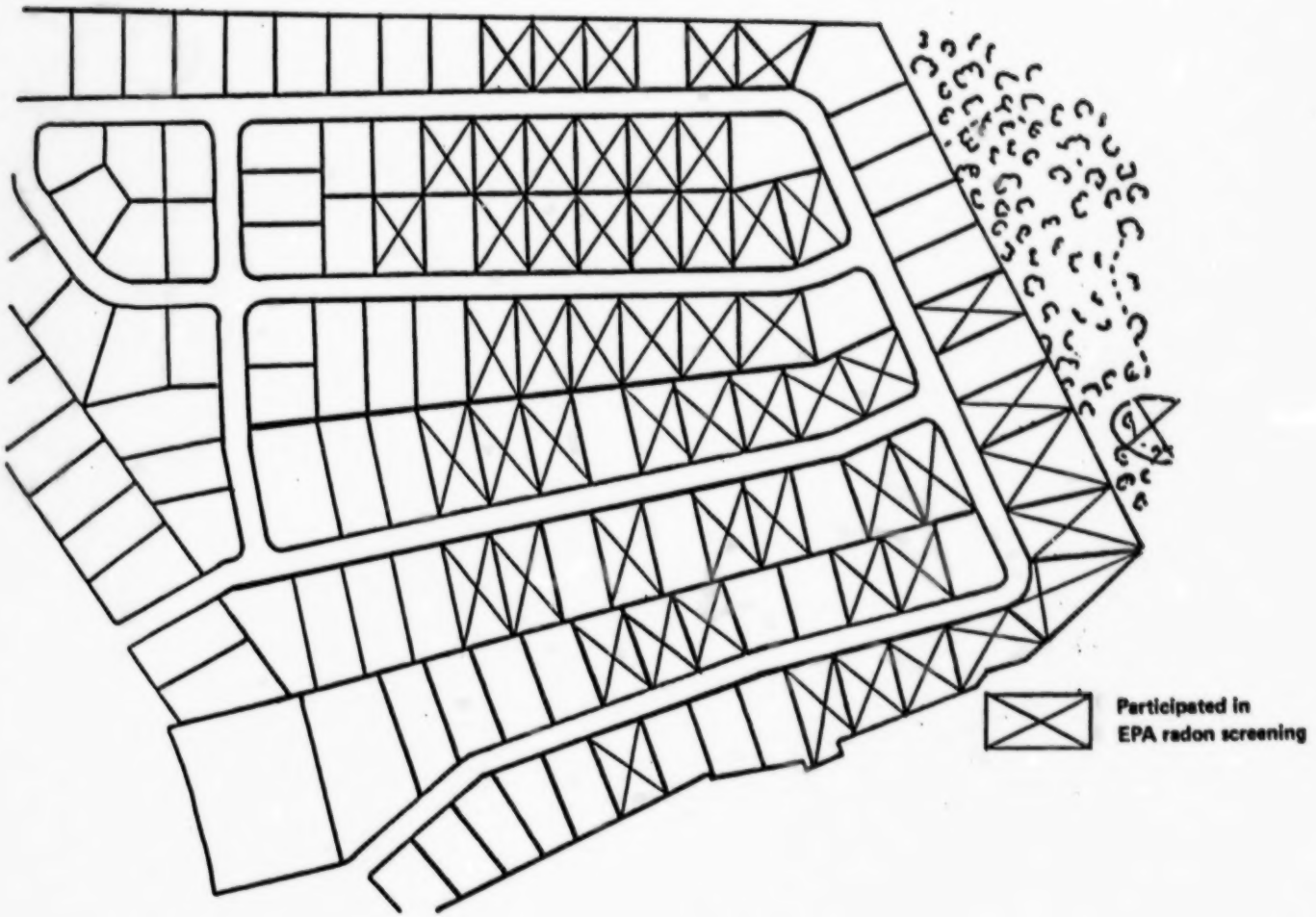

Figure 1. Houses selected for radon screening.

Table II shows the distribution by floorplan of the homes selected for the demonstration study. All of these homes had radon concentrations in excess of 200 pCi/l in the DEP screening, and four of the houses had concentrations in excess of 1000 pCi/l.

Table II. Distribution of houses selected for demonstration.

Construction Design (substructure)	House No.
Split Level (combination slab-on-grade and block basement)	C8A C30A C39A C46A
Bi-level (slab-below-grade)	C10B C31B C48B
2-Story (slab-on-grade) (block basement)	C33C C32D
Other (combination slab-on-grade and dirt crawl space)	C24E

RADON MONITORING TECHNIQUES

Three radon monitoring techniques were used during this program: radon grab sampling using Pylon* flowthrough scintillation cells, continuous radon monitoring using a Pylon AB-5 monitor together with a passive radon scintillation cell detector (PRD), and an integrating short-term technique using charcoal canisters. Protocols for the use of these techniques are detailed in the Quality Assurance Project Plan (QAPP) for this project and are not repeated in this paper.

Radon Grab Sample Measurements

Radon grab samples were obtained using a Pylon flowthrough scintillation cell attached to a Pylon AB-5 monitor fitted with a Lucas cell

*Registered trade mark of Pylon Electronic Development Company

adapter. Procedures described in the EPA document "Interim Indoor Radon and Radon Decay Products Measurement Protocols[2] were followed. Grab samples were used to identify suspected soil gas entry routes. In all houses with sump holes, grab samples were taken in the stream of air exiting the footing drain pipe. Other common locations for effective grab sample collection were:

- Air space in unpaved crawl spaces
- Wall cavities
- Inside open cinder blocks
- Air exiting a hole drilled in a concrete block wall or slab floor
- Air in subslab heating ducts

Although grab sampling can be misleading, in conjunction with other measurements, it proved very useful in identifying major soil gas entry routes.

If the grab sample concentration can be combined with the measurement of soil gas flowrate from an opening to the soil, a source strength can be calculated for the conditions under which the measurement was taken. The concentration and flowrate are dynamic and are affected by air pressure differentials, snow cover, precipitation, and even time of day. An example source term calculation was made for house C30A. A soil gas flowrate of 90 ft^3/h (2,500 l/h) was measured entering the building from the footing drains in the sump hole. The radon concentration in a grab sample of the air from the sump hole was 36,000 pCi/l. Under the measurement conditions (approximately 2 to 3 Pa of negative pressure due to both the furnace and clothes dryer operation), this measurement corresponded to a source term of over 91 million pCi/h and would account for an indoor concentraton of between 600 and 1,200 pCi/l given an air exchange rate of from 0.5 to 1.0 air changes per hour (ACH). Because air concentrations of radon were from 1,400 to 2,700 pCi/l in this house, the sump hole was considered to be the largest but not the only source of soil gas infiltration to the house.

Efforts were made to measure the difference in pressure between the inside and outside of the house while grab samples were being taken. Because factors such as windspeed and furnace or fan operation can affect the flow of soil gas substantially, pressure difference information allows a reasonable interpretation of seemingly anomalous radon grab sample results and results from other techniques designed to determine the rate and location of radon entry. Pressure differences were measured using 0.005 to 0.25 in. (0.127 to 6.35 mm) range Magnehelic gauges.

Continuous Radon Monitoring

Continous monitoring results were helpful in understanding the daily variations in radon concentration in a house and how this pattern, as well as overall radon levels, were affected by natural and powered ventilation, heating systems, and other factors that might influence

radon levels.

The ability of the passive monitoring system to respond to temporal variations in radon concentration was tested in the Department of Energy, Environmental Measurement Laboratory's (EML's) exposure chamber. In all cases, the field monitoring device was able to track the laboratory equipment response to concentration changes reliably.

The continuous monitoring system was set to count collected air samples at 30-minute intervals. Three 48-hour sampling periods were used to monitor pre- and post-radon reduction gas concentrations.

Charcoal Canister Monitoring

Short-term integrating monitoring, using activated charcoal, is most commonly used in radon screening and assessment studies. In addition, the simplicity and low cost of charcoal canister monitoring made it an attractive confirmatory measurement technique in the current work. The canisters and continuous monitoring devices were routinely deployed simultaneously in the same locations to allow comparison of monitoring results.

In the Clinton houses, radon concentrations varied by as much as a factor of 20 in a 24-hour period prior to the installation of radon reduction equipment. The ability of charcoal canisters to provide reliable measurement information under these conditions is uncertain. George[3] describes tests of the response by charcoal canisters to radon concentrations that varied by two times the lowest concentration during the monitoring period. Analyses of the canisters found radon concentrations to be representative of the average chamber concentration. Unfortunately, reports of tests at the larger concentration differences encountered in Clinton have not been located in a review of the literature.

INVESTIGATION OF BASEMENT DEPRESSURIZATION

In the majority of houses, differential air pressure between basement air and outside air was measured. Temperature-driven stack effects and mechanical equipment effects were isolated, and the induced pressure differences were measured. Pressure difference measurements for two houses are listed in Table III. It was found that:

- Dryers and bathroom fans resulted in a 1 Pa or less negative pressure on a basement.
- Furnaces in the 100,000 to 120,000 Btu/hr (1.055×10^8 - 1.266×10^8 J) range put 2 to 3 Pa negative pressure on a basement.
- Differential temperatures of 20 to 30 °F (11 to 17°C) resulted in 1 - 3 Pa negative pressure on a basement.

Table III. Pressure difference measurements for two houses.

House C46A	
House closed, outside temp. = 62°F (16.6°C) inside temp. = 67°F (19.4°C)	0 Pa
Dryer + bath fan on	1 Pa
Furnace + dryer + bath fan on	2 Pa
Furnace + dryer + bath fan on inside temp. = 80°F (26.7°C)	3 to 4 Pa
House C48B	
House closed, outside temp. = 62°F (16.6°C) inside temp. = 64°F (17.8°C)	0 Pa
Furnace on, inside temp. = 93°F (33.8°C)	4 Pa
Furnace on, inside temp. = 93°F (33.8°C) + attic hatch opened	5 to 6 Pa

During the pressure measurements described above with a furnace running, makeup air was drawn from the attic down the cavity around the chimney. In building C48B this amounted to approximately 50 CFM (1.4 m^3/min). Measurement of the airflow from the furnace exhaust at the chimney top showed airflow rates of between 100 and 200 CFM (2.8-4.3 m^3/min). Figure 2 (a fan-flow curve for House C48B) shows an induced negative pressure of 1 to 2 Pa at 200 CFM (4.3 m^3/min), reflecting the pressure difference actually measured in the house when neither the furnace nor the clothes dryer was in operation. Blower door generated fan-flow curves (as measured with blower door tests) were found to be useful in estimating the volume of makeup air required to compensate for basement negative pressures. The curves, when put to this use, were most accurate when generated from data collected with the blower door placed in a basement access door.

To reduce a negative pressure of 3 to 4 Pa to 0 Pa it was found that 7-10 ft^2 (0.65-0.93 m^2) of window area must be opened to the outside.

It is difficult to make low pressure measurements in the field. Field instruments are reliable only to a lower limit of about 1 Pa. Even low windspeeds have a large impact on the pressure fields surround-

ing a house. Measurements were made when windspeeds were undetectable to avoid the confounding effects of wind. Toward the end of the diagnostic work, these measurements were made using a more sensitive electronic device assembled using components purchased from Modus Instruments (481 Gleason Rd., Stow, MA 01775). This system has a lower detection limit of 0.25 Pa.

A test was made to gain some insight into the potentially competing effects of increased soil gas entry versus added dilution air when a whole house fan was used for ventilation. The results are shown in Figure 3. Although the fan dramatically increased ventilation, 2,000 CFM (57 m^3/min), the large negative pressure differential (28 Pa) increased the rate of soil gas entry sufficiently to overwhelm the diluting effect. This test was made in only one house, and the results depend on factors that may be peculiar to the individual building's soil gas characteristics.

RESULTS

The concentration of radon measured in a house is strongly dependent on the condition under which the measurement is made. The ideal conditions for measuring high radon concentrations are those found in winter, when doors and windows are closed for long periods and thermally driven negative pressure is applied at soil contact points. A statistical study of available monitoring data conducted by EPA found that radon measurement variance was lowest when houses were monitored in the winter[4]. This study led to the recommendation that winter conditions be simulated when monitoring for radon. Efforts to simulate winter conditions using a variety of techniques were at best unreliable.

Radon concentrations in houses show both a daily and seasonal variation. Measurements were taken within the 2 week period immediately preceding installation of radon reduction equipment wherever possible. Post-radon reduction measurements were made as soon after installation of the reduction equipment as possible. It was hoped that this short time delay between pre- and post-radon reduction measurements would reduce the effect of seasonal variations on the measurement; however, in some of the houses requiring three levels of mitigation, this was not possible. Pre-radon reduction continous monitor measurements were made in full summer, while post-radon reduction continuous monitor and charcoal measurements were made in November through January. Baseline data collected under attempted simulated winter conditions did not produce radon levels comparable to those measured during the DEP radon survey in most cases. Initial continuous monitor data were collected when radon levels were at a seasonal low, and the data after radon reduction were collected when indoor radon levels were increasing due to the onset of winter. Consequently, in some cases, interpretation of radon reduction effectiveness via continous monitor data was inconclusive. Results of the radon reduction efforts in Clinton as shown in Table IV include only charcoal canister data except where specifically noted.

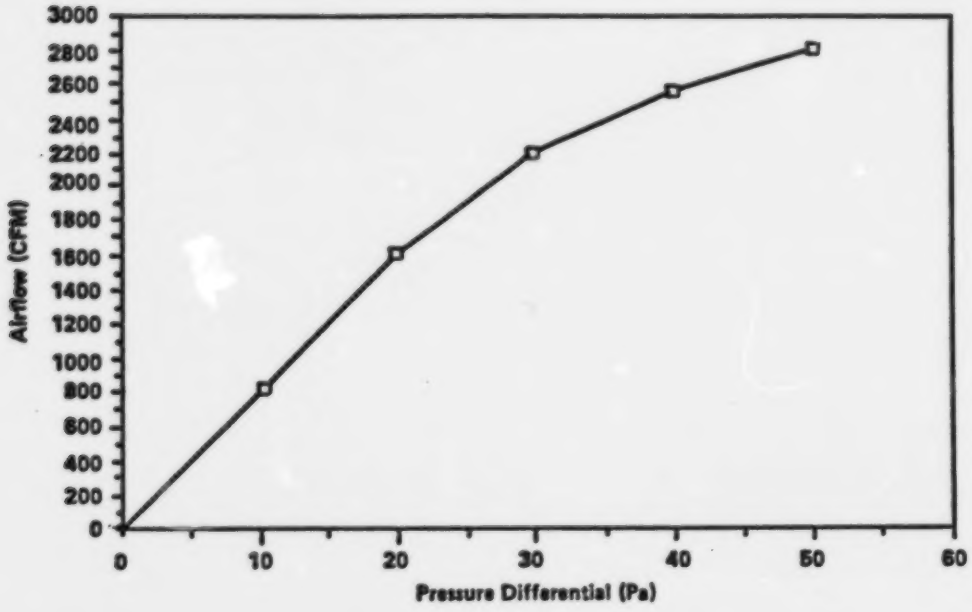

Figure 2. Fan flow curve for house C48B.

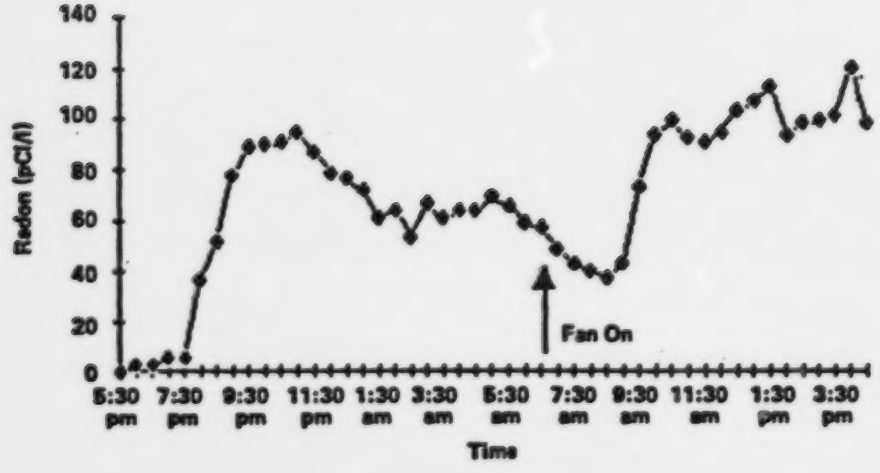

Figure 3. Effect of whole house fan use with all windows open on radon concentration.

Table IV. Approximate reduction in radon concentrations following application of radon reduction techniques.

(pCi/l)

House No.	Before Radon Reduction (Early Spring) (DEP)*	Before Radon Reduction (Summer) (Closed House)	After Radon Reduction** (Late Fall) (Closed House)	Minimum Percent Reduction	Maximum Percent Reduction
C30A	2,254	1,450	4.1	99.7	99.8
C39A	1,500	10.4 (1,250 w/Pylon)	4.3	58.7	99.7
C8A	791	409	2.9	99.3	99.6
C46A	635	772	9.0	98.6	99.2
C10B	418	15.8 (70 w/Pylon)	16.0	0	96.2
C31B	691	89.0	5.8	93.5	99.2
C48B	936	771	11.1	98.6	98.8
C33C	1,190	304	4.7	98.5	99.7
C32D	1,357	29.0	11.3	61.0	99.2
C24E	426	91.0 (210 w/Pylon)	12.3	86.5	97.2

* DEP screening study charcoal canister measurements taken in March and April of 1986.

** Charcoal canister measurements taken in November 1986 through January 1987.

CONCLUSIONS

Both the temperature-driven stack effect and typical household appliances such as furnaces, whole-house fans, clothes dryers, and bathroom fans were observed to reduce indoor pressure and potentially increase radon levels. Radon measurements obtained during cold weather after residential heating systems were back in full operation showed that the radon reduction techniques that were applied had been effective and radon concentrations were significantly reduced. Although both grab sample and continuous monitor measurements were helpful in assessing radon entry sites and hour-to-hour radon fluctuations, respectively, only charcoal canister data collected under near-winter conditions could be used as a valid comparison with the DEP March/April generated pre-radon reduction data.

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[1]U.S. Environmental Protection Agency, Office of Air and Radiation, "A Citizen's Guide to Radon: What It Is and What To Do About It," OPA-86-004, August 1986.

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